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# RAPID CALCULATION TECHNIQUES FOR RADAR PERFORMANCE PREDICTIONS



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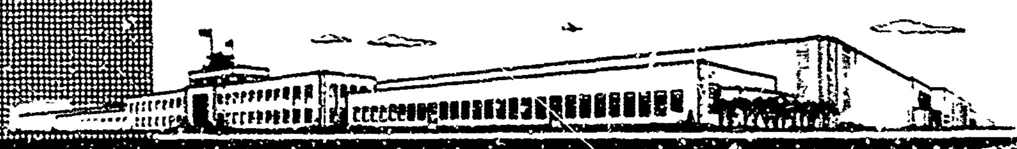

NAVAL AVIONICS FACILITY

INDIANAPOLIS, INDIANA 46218



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# RAPID CALCULATION TECHNIQUES FOR RADAR PERFORMANCE PREDICTIONS





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## ABSTRACT

This report provides a work form and rationale to perform hand calculations of the radar range equation. The techniques described cover the conventional geometric aspects of the radar equations as well as the effects of rain clutter, rain attenuation, atmospheric attenuation, sea and land clutter, and pulse integration for both conventional pulse and chirp radar. The report is designe[illegible] be complete within itself, requiring no further texts, tables, references or slide rules.

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## I. INTRODUCTION

In the evaluation of the detection performance of a radar system, it is necessary to use the radar equation in one of its many forms. Unfortunately the mixture of units and the calculation of clutter effects defy convenient manipulation. However, with certain simplifying assumptions and limitations, one can develop equations which can be used conveniently by hand. The calculation techniques in this report cover the effects of rain clutter, rain attenuation, atmospheric attenuation, sea clutter, land clutter and pulse integration as well as the conventional geometric aspects.

The limiting assumptions are: the depression (or elevation) angle must be less than 10°, the slant range must be greater than 3 nautical miles, and the radar and target altitude should be less than 10,000 feet. These limits are imposed by certain geometric simplifications. Fortunately, the majority of radar applications fall well within these limitations.

The goal of this report is to allow an evaluation to be made without further reference to any aids, including charts, tables or slide rule. These techniques were originally developed at NAFI in order to more fully assess a radar design during meetings and conferences.

Other, more general techniques, as well as a more complete discussion of many of the parameters and their effect on a radar system can be found in the following NAFI reports: "Simplified Radar Calculation Techniques" NAFI TR-917, and "Computer Aided Radar Design" NAFI TR-1461.

Most of the calculations in this report use decibels to facilitate division, multiplication and root extractions. Numerous simplified tables are included to estimate integration, attenuation and clutter effects. The major radar parameters calculated include maximum range, integrated signal to noise, signal to weather clutter, signal to land clutter and signal to sea clutter ratio. These ratios may be combined to yield the integrated signal to noise plus weather plus sea or land clutter ratio for any specified range and target.

The calculation of the integrated signal to noise plus clutter ratio is performed in two parts. The first part uses Section A to determine an estimate of the maximum range without any clutter or weather effects. The second part uses Section B to calculate the integrated signal to noise plus clutter ratio with clutter and weather effects at a particular range. Most calculations are in decibels and a foldout decibel to ratio conversion table is given in Appendix A to help the user. Section A and section B are work forms for calculation of maximum range and signal to noise plus clutter ratio, respectively.

Appendix B presents the mathematical derivation of the simplified equations used in sections A and B. Appendix C is an example of the usage of the work forms.

## II. CALCULATIONS

### A. MAXIMUM RANGE ESTIMATION

#### 1. Single Pulse

| Parameter | Value | Units | db Representation | Multiply By | Add db Results |
|---|---|---|---|---|---|
| $P_k$ : Peak Power | | KW | | +1 | |
| $\lambda$ : Wavelength | | cm | | +2 | |
| $\sigma_T$ : Target RCS | | $M^2$ | | +1 | |
| G : Antenna Gain | | db → | → | +2 | |
| L : Losses | | db → | → | -1 | |
| B : Bandwidth | | MHz | | -1 | |
| $\overline{NF}_o$ : Noise Figure | | db → | → | -1 | |
| (S/N): Signal/Noise | | db → | → | -1 | |
| Conversion Factor | → | → | → | → | -30 |

4 db nautical miles = $SUM_{4R}$ = ________ db

The maximum range (N miles) is obtained by multiplying the $SUM_{4R}$ decibel by $\frac{1}{4}$ and expressing this as a ratio:

Maximum Range Estimation = __________ NM

#### 2. Comments

a. Chirp Systems

(1). Use peak transmitter power (as at the antenna)

(2). Use the narrow, unchirped bandwidth

b. Antenna Gain

(1). If aperture only is given, see table in Appendix A.

c. Losses

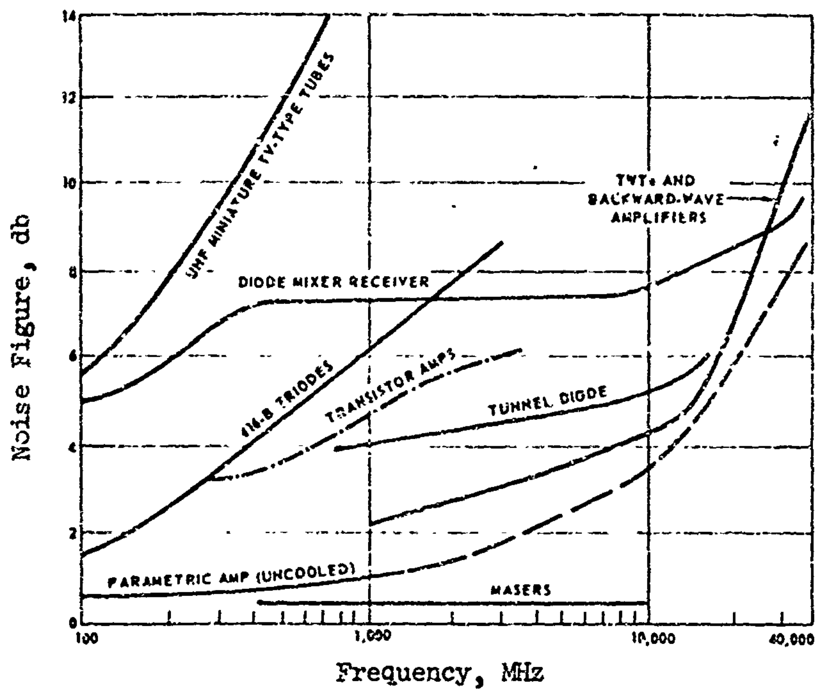
(1). Typical value for search radar 16 db, minimum value 10 db.

(2). Losses included are:

| | | Minimum db |
|---|---|---|
| $L_c$ | collapsing | 2 |
| $L_i$ | integration | 1 |
| $L_e$ | gate or filter overlap | 0 |
| $L_g$ | threshold | 1 |
| $L_d$ | scan distribution | 1 |
| $L_f$ | target | 0 |
| $L_n$ | antenna efficiency | 0 |
| $L_m$ | filter matching | 1 |
| $L_o$ | post detection integration | 1 |
| $L_p$ | antenna pattern | 1 |
| $L_r$ | receiving loss | 1 |
| $L_t$ | transmitting loss | 1 |
| $L_s$ | scanning loss | 0 |
| | | 10 db |

d. Signal to Noise Ratio (S/N). Typical value: 12db. This provides a probability of detection of about 90 percent with a false alarm ratio of .0001. For other values see Appendix A.

e. Noise Figure. The following table gives the minimum noise figures that may be expected from different types of detectors. Actual values that may be expected from equipment in the field exceed these values by about 40 percent.




f. PRF Limited Range

| Parameter | Value | Units | db Representation | Multiply By | Add db Results |
|---|---|---|---|---|---|
| PRF | | pulses/sec | | -1 | |
| Conversion Factor | | | | | +49.2db |

$U_{db}$, Unambiguous decibel range = _____ db

The PRF limited range is the ratio representation of the Unambiguous decibel range, $U_{db}$. Therefore, PRF Limited Range = ___________ NM

B. <u>CALCULATION OF</u> $\left(\frac{S}{N + C_\omega + C_{S/L}}\right)_i$ <u>RATIO</u>

1. <u>Preliminary Information for</u> $\left(\frac{S}{N + C_\omega + C_{S/L}}\right)_i$ <u>Calculation</u>

Limitations: Radar height less than 10,000 feet.

Target height less than 10,000 feet.

Depression angles less than 10 degrees.

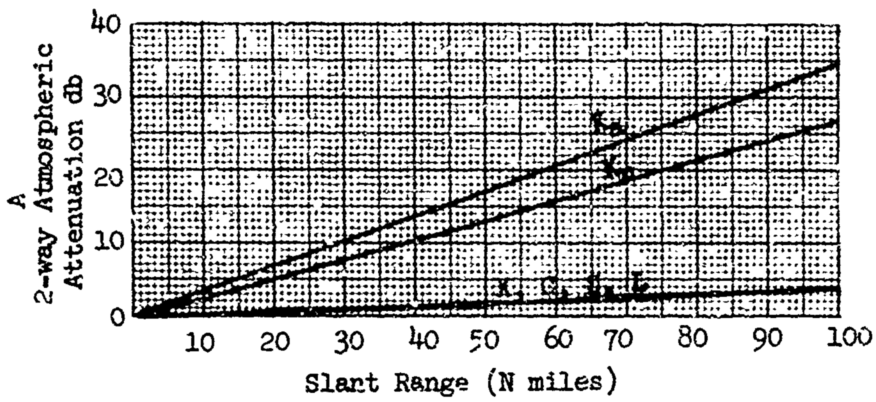
Slant ranges greater than 3 N miles

a. Slant Range, R = ________ n miles

Radar Height, h = ________ (100's feet)

Depression angle, $\theta°$, = $\frac{h \text{ (100's ft)}}{R \text{ (n miles)}}$ = ________ degrees.

b. Atmospheric Attenuation, A = ________ db.



c. Rain Attenuation

(1)

| Parameter | Value | Units | db Representation | Multiply By | Add db Results |
|---|---|---|---|---|---|
| R : Range | | NM | | +1 | |
| W : Rain Rate | | mm/hr | | +1 | |
| λ : Wavelength | | cm | | -2 | |
| Factor | | | | | -1.42 |

$SUM_R$ = ________ db

(2)

| Parameter | Value | Units | Ratio Representation | $A_R$ |
|---|---|---|---|---|
| $SUM_R$ | | db | | |

$A_R$, 2-way Rain Attenuation = ________ db

2. Calculation of (S/N)i

a. Single Pulse $(S/N)_1$

| Parameter | | Value | Units | db Representation | Multiply By | Add db Results |
|---|---|---|---|---|---|---|
| $P_k$ | : Peak Power | | Kw | | +1 | |
| $\lambda$ | : Wavelength | | cm | | +2 | |
| $\sigma_T$ | : Target RCS | | $M^2$ | | +1 | |
| G | : Antenna Gain | | db | → | +2 | |
| L | : Losses | | db | → | -1 | |
| A | : Atmospheric Attenuation | | db | → | -1 | |
| $A_R$ | : Rain Attenuation | | db | → | -1 | |
| $\overline{NF}_o$ | : Noise Figure | | db | → | -1 | |
| B | : IF Bandwidth | | MHz | | -1 | |
| R | : Range | | NM | | -4 | |
| | Factor → | | | | | -30.0 |

$(\frac{S}{N})_1$ = ________ db

b. Integration Improvement (Assuming visual PPI detection)

PRF = ________ pulses/second

AZ° = ________ degrees

SCAN RATE ________ degrees/second

number of Hits/Scan, #H = $\frac{(PRF)(AZ°)}{(SCAN\ RATE)}$ = ________ Hits/Scan

| #H, (Hits/Scan) = | 5 | 10 | 15 | 20 | 25 | 30 | 40 | 50 | 60 |
|---|---|---|---|---|---|---|---|---|---|
| I, Integration Improvement in db = | 6 | 8.4 | 9.6 | 10.5 | 11.2 | 11.8 | 12.6 | 13.2 | 13.8 |

Integration Improvement, I = ________ db

c. Integrated $(S/N)_1$

$$\left(\frac{S}{N}\right)_i = \left(\frac{S}{N}\right)_1 (db) + Idb = \_\_\_\_\_\_ db$$

3. Calculation of $\left(\frac{S}{C_\omega}\right)_i$

a. Single Pulse $(S/C_\omega)_1$

| Parameter | Value | Units | db Representation | Multiply By | Add db Results |
|---|---|---|---|---|---|
| $\sigma_T$ : Target RCS | | $M^2$ | | +1 | |
| $\lambda$ : Wavelength | | cm | | +4 | |
| W : Rain Rate | | mm/hr | | -1.6 | |
| AZ : AZ Beamwidth | | deg. | | -1 | |
| EL : EL Beamwidth | | deg. | | -1 | |
| $\tau$ : Pulse Length | | $\mu$ sec | | -1 | |
| R : Range | | NM | | -2 | |
| Factor → | | | | | + 4.87 db |

$(S/C_\omega)_1 =$ ________ db

b. Integration Factor

Integration Improvement, I, from 2b. = ________ db

c. Pulse Compression Ratio

Pulse Compression Ratio = ________ unitless

The Pulse Compression Factor, CR, is the decibel representation of the unitless Pulse Compression Ratio.

Therefore, Pulse Compression Factor, CR = ________ db

d. Integrated $(S/C_\omega)_i$

$$\left(\frac{S}{C_\omega}\right)_i = \left(\frac{S}{C_\omega}\right)_{1db} + I_{db} + CR_{db} = \underline{\qquad\qquad} \text{ db}$$

4. Calculate $\left(\frac{S}{C_{S/L}}\right)_i$

a. Clutter Reflectivity

(1). Depression Angle, θ, from 1a. = _______ deg.

Radar Band = __________

Clutter Type = __________

Clutter Reflectivity, $\sigma_c$, from Clutter values Appendix A. =____db.

(2). Pulse Compression Effect:

| Parameter | Value | Units | Multiply By | Add db Results |
|---|---|---|---|---|
| $\sigma_o$ : Clutter Reflectivity | | +db | -1 | |
| CR : From Sec. 3c. | | +db | -1 | |

$\sigma_o$(EFF), Effective Clutter Reflectivity = _______db.

b. Single Pulse $\left(\frac{S}{C_{S/L}}\right)_1$

| Parameter | Value | Units | db Representation | Multiply by | Add db Results |
|---|---|---|---|---|---|
| $\sigma_T$ : Target RCS | | $M^2$ | | +1 | |
| τ : Pulse Length | | μsec | | -1 | |
| R : Range | | NM | | -1 | |
| AZ : AZ Beamwidth | | deg. | | -1 | |
| $\sigma_o$(EFF): From Sec. 4a. | | db → | → | -1 | |
| Factor → | → | → | → | → | -35.35 db |

Single Pulse $\left(\frac{S}{C_{S/L}}\right)_1$ = ________db

c. Integrated $\left( \frac{S}{C_{S/L}} \right)_i$

$\left( \frac{S}{C_{S/L}} \right)_1$ (from Sec. 4b.) = ________db

I (From Sec. 2b.) = ________db

$\left( \frac{S}{C_{S/L}} \right)_i = \left( \frac{S}{C_{S/L}} \right)_1 + I$ = ________db

5. <u>Calculate</u> $\left( \frac{S}{N + C_\omega + C_{S/L}} \right)_i$

a. Calculate "Energy" Ratio

| Parameter | Value | Units | Multiply By | Add Ratio Representation |
|---|---|---|---|---|
| $(S/N)_i$: Section 2c. | | db | -1 | |
| $(S/C_\omega)_i$: Section 3d. | | db | -1 | |
| $(S/C_{S/L})_i$: Section 4c. | | db | -1 | |

E, Inverse "Energy" Ratio = ________ unitless

b. Integrated $\left( \frac{S}{N + C_\omega + C_{S/L}} \right)_i$

| Parameter | Value | Units | db Representation | Multiply By | $\left( \frac{S}{N+C_\omega+C_{S/L}} \right)_i$ db |
|---|---|---|---|---|---|
| E, Sec. 5a. | | unitless | | -1 | |

$\left( \frac{S}{N + C_\omega + C_{S/L}} \right)_i$ = ________db

# APPENDIX A

## SIMPLIFIED RADAR DATA

A. Signal to Noise Ratio VS Probability of Detection

| $\left(\frac{S}{N + C_{\omega} + C_{S/L}}\right)_i$ | Probability of Detection | Probability of False Alarm |
|---|---|---|
| 4 db | 99 % | |
| | 90 | .50 |
| | 80 | .25 |
| | 50 | .05 |
| 8 db | 99 | .30 |
| | 90 | .05 |
| | 80 | .02 |
| | 50 | .01 |
| 12db | 99 | $5 \times 10^{-2}$ |
| | 90 | $10^{-4}$ |
| | 80 | $10^{-5}$ |
| | 50 | $10^{-7}$ |
| 16 db | 99.9 | $10^{-7}$ |
| | 99 | $10^{-10}$ |
| | 90 | $10^{-13}$ |
| | 80 | $10^{-14}$ |

B. Clutter Reflectivity: $\sigma_o$ in db below one square meter

**Ka Band 35 GHz**

| Clutter | Grazing Angle .1° | .3° | 1° | 3° | 10° |
|---|---|---|---|---|---|
| Seastate 1 | | | 43 | 41 | 38 |
| 3 | | | 34 | 34 | 31 |
| 5 | | | 31 | 30 | 26 |
| Desert | | | | | 22 |
| Farm Land | | | | 23 | 20 |
| Wooded | | | | 13 | 19 |
| City | | | | | |

**Ku Band 17 GHz**

| Clutter | Grazing Angle .1° | .3° | 1° | 3° | 10° |
|---|---|---|---|---|---|
| Seastate 1 | | | 47 | 43 | 40 |
| 3 | | | 37 | 36 | 32 |
| 5 | | 39 | 32 | 31 | 26 |
| Desert | | | | | 26 |
| Farm Land | | | 23 | | 23 |
| Wooded | | | 20 | | 20 |
| City | | | | | |

**X Band 10 GHz**

| Clutter | Grazing Angle .1° | .3° | 1° | 3° | 10° |
|---|---|---|---|---|---|
| Seastate 1 | 65 | 58 | 50 | 45 | 42 |
| 3 | 51 | 45 | 39 | 38 | 32 |
| 5 | 44 | 39 | 33 | 31 | 26 |
| Desert | | | 38 | | 26 |
| Farmland | | | 36 | | 25 |
| Wooded | | | 30 | | 23 |
| City | | | 24 | | 12 |

**C Band 5.6 GHz**

| Clutter | Grazing Angle .1° | .3° | 1° | 3° | 10° |
|---|---|---|---|---|---|
| Seastate 1 | 75 | 60 | 53 | 49 | 44 |
| 3 | 56 | 48 | 43 | 40 | 34 |
| 5 | 48 | 41 | 35 | 33 | 28 |
| Desert | | | | | |
| Farmland | | | 38 | | 29 |
| Wooded | | | 35 | | |
| City | | | | | |

**S Band 36 GHz**

| Clutter | Grazing Angle .1° | .3° | 1° | 3° | 10° |
|---|---|---|---|---|---|
| Seastate 1 | 80 | 62 | 56 | 52 | |
| 3 | 68 | 55 | 48 | 43 | 34 |
| 5 | 53 | 50 | 38 | 35 | 28 |
| Desert | | | | 30 | 28 |
| Farmland | | | | | 21 |
| Wooded | | | | 33 | 25 |
| City | | | | | 18 |

**L Band 1.25 GHz**

| Clutter | Grazing Angle .1° | .3° | 1° | 3° | 10° |
|---|---|---|---|---|---|
| Seastate 1 | | | 65 | 53 | 54 |
| 3 | 82 | | 54 | 43 | 34 |
| 5 | 65 | | 43 | 38 | 28 |
| Desert | | | | 45 | 40 |
| Farmland | | | | 32 | 33 |
| Wooded | | | | 34 | 23 |
| City | | | | 30 | 18 |

C. ANTENNA CHARACTERISTICS

1. Beamwidth Calculations

a. Azimuth Beamwidth

| Parameter | Value | Unit | db Representation | Multiply By | Add db Results |
|---|---|---|---|---|---|
| Wavelength | | cm | | +1 | |
| Antenna Width | | ft | | -1 | |
| Conversion Factor | → | → | → | → | +4.3 db |

Decibel Antenna Beamwidth, $AZ_{db}$ = ________ db

b. Elevation Beamwidth

| Parameter | Value | Unit | db Representation | Multiply By | Add db Results |
|---|---|---|---|---|---|
| Wavelength | | cm | | +1 | |
| Antenna Height | | ft | | -1 | |
| Converstion Factor | → | → | → | → | +4.3 db |

Decibel Antenna Beamwidth, $EL_{db}$ = ________ db

The antenna beamwidths in degrees are the ratio representation of the decibel antenna beamwidth. Therefore,

AZ° = ________ degrees

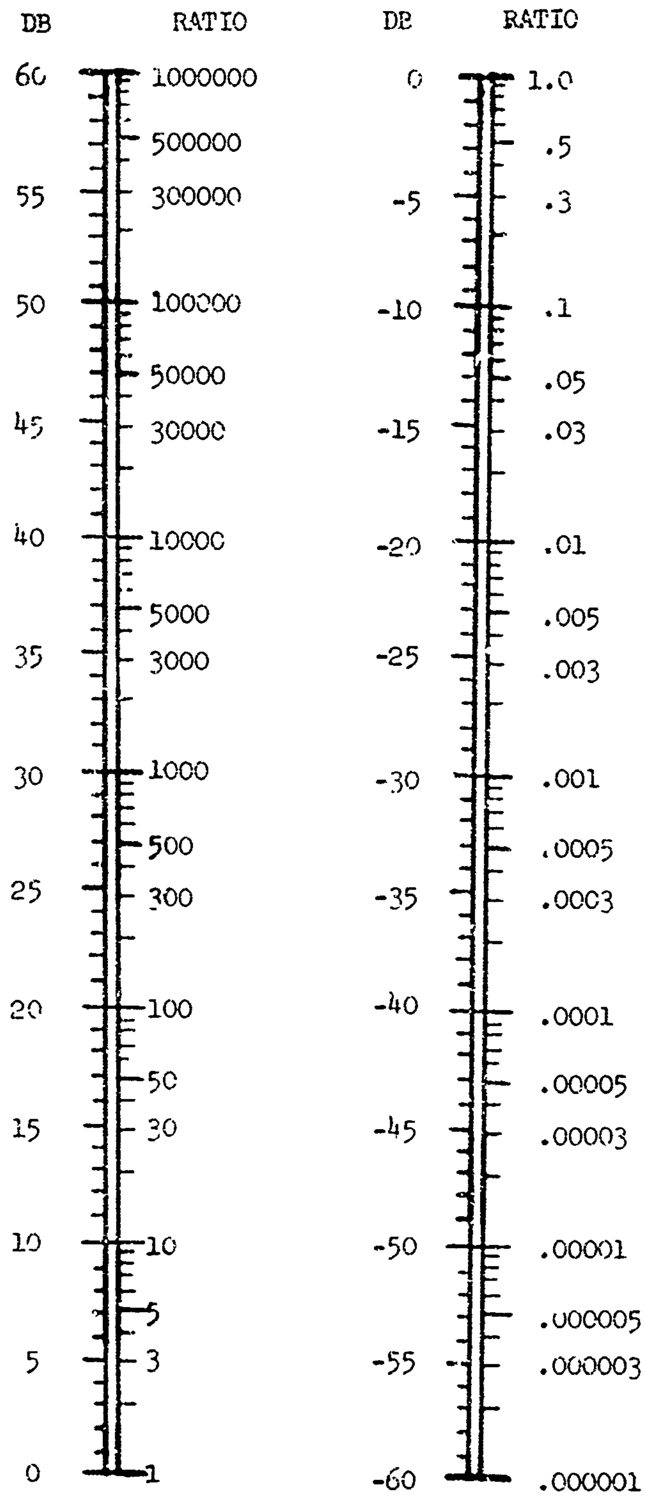
EL° = ________ degrees

2. Antenna Gain Calculation

| Parameter | Value | Units | db Representation | Multiply By | Add db Results |
|---|---|---|---|---|---|
| AZ° | | deg. | | -1 | |
| EL° | | deg. | | -1 | |
| Conversion Factor | → | → | → | → | +44.3db |

Antenna Gain, G = ________ db

D. DECIBEL TO RATIO CONVERSION TABLE


DB
RATIO
60
1000000
500000
55
300000
50
100000
50000
45
30000
40
10000
5000
35
3000
30
1000
500
25
300
20
100
50
15
30
10
10
5
5
3
0
1
DB
RATIO
0
1.0
.5
-5
.3
-10
.1
.05
-15
.03
-20
.01
.005
-25
.003
-30
.001
.0005
-35
.0003
-40
.0001
.00005
-45
.00003
-50
.00001
.000005
-55
.000003
-60
.000001



B

# APPENDIX B

## SIMPLIFIED MATHEMATICAL DERIVATION FOR $\left(\frac{S}{N + C_\omega + C_{S/L}}\right)_i$

The derivation of the equations used in this report are in NAFI TR-1461. The decibel equation form used is as given in NAFI TR-917. The following derivations are a summary of some of the equations in these two reports.

A. SINGLE PULSE SIGNAL TO NOISE RATIO

$$\left(\frac{S}{N}\right)_1 = \left(\frac{P\lambda^2}{BR^4}\right) \sigma_T \, 10^{(2G - L - A_R - \overline{NF}_o)/10} \times 10^3 \qquad \text{(B.1)}$$

where

$S$ = Signal Power Watts
$N$ = Noise Power Watts
$P$ = Peak Power, kw
$\lambda$ = Wavelength, cm
$\sigma_T$ = Target RCS, $M^2$
$B$ = IF Noise Bandwidth, MHz
$R$ = Slant Range, NM
$G$ = Antenna Gain, db
$L$ = System Losses, db
$A_R$ = Rain Losses, db
$A$ = Atmospheric Attenuation, db
$\overline{NF}_o$ = Noise Figure, db

B. WEATHER CLUTTER BACKSCATTER

$$\sigma_\omega = \frac{W^{1.6} \, AZ^\circ \, EL^\circ \, R^2 \, \tau}{\lambda^4} \; .32549 \; (M^2)$$

$$\left(\frac{C_\omega}{N}\right)_1 = \left(\frac{S}{N}\right)_1 \frac{\sigma_\omega}{\sigma_T}$$

therefore

$$\left(\frac{S}{C_\omega}\right)_1 = \frac{\sigma_T}{\sigma_\omega}$$

Therefore, signal to weather clutter ratio:

$$\left(\frac{S}{C_\omega}\right)_1 = \frac{\sigma_T \quad \lambda^4 \qquad 3.072}{W^{1.6}\ AZ^\circ\ EL^\circ\ R^2\ \tau} \tag{B.2}$$

where:

$C_\omega$ = Weather clutter backscatter power, watts
$\sigma_\omega$ = Weather clutter reflective area, $M^2$
W = Rain Rate, MM/Hour
AZ° = Antenna azimuth beamwidth, degrees
EL° = Antenna elevation beamwidth, degrees
$\tau$ = Pulse length, $\mu$ seconds

C. SEA OR LAND CLUTTER RETURN

$$\sigma_{S/L} = \frac{AZ^\circ\ R\ \tau}{\text{Cos } E}\ 3427.1\ \ 10^{(\sigma_o/10)}\ (M^2)$$

Assume: pulse width limited clutter

Assume: depression angle, E, is less than 10° so Cos E = 1

Therefore,

$$\sigma_{S/L} = AZ^\circ\ R\ \tau\ 10^{(\sigma_o/10)}\quad 3427.1\ \ M^2$$

$$\left(\frac{S}{C_{S/L}}\right) = \frac{\sigma_T}{\sigma_{S/L}}$$

$$\left(\frac{S}{C_{S/L}}\right) = \frac{\sigma_T \quad 2.917}{AZ^\circ \; R \; \tau \; 10^{(\sigma_o/10)}} \times 10^{-4} \qquad (B.3)$$

where

$\sigma_{S/L}$ = Sea or land clutter area, $M^2$

$\sigma_o$ = Clutter reflectivity, $db_{M^2}$

E = Depression angle, degrees

$C_{S/L}$ = Sea or land clutter return, watts

D. INTEGRATED $\left(\frac{S}{N + C_\omega + C_{S/L}}\right)_i$ RATIO

$$\left(\frac{S}{N + C_\omega + C_{S/L}}\right)_i \equiv 10 \log \left(\frac{S}{N + C_\omega + C_{S/L}}\right) + I(\text{in db})$$

Where: I = Integration Improvement, db

Let: $I_F$ = Integration Improvement Ratio = $10^{(I/10)}$, unitless

Derivation: Using Equations (B.1), (B.2) and (B.3), the integrated signal to noise plus weather clutter plus sea or land clutter ratio may be written as:

$$\frac{S}{N + C_\omega + C_{S/L}} = \frac{1}{\frac{N}{S} + \frac{C_\omega}{S} + \frac{C_{S/L}}{S}}$$

$$\frac{S}{N + C_\omega + C_{S/L}} = \frac{1}{\frac{1}{(\frac{S}{N})} + \frac{1}{(\frac{S}{C_\omega})} + \frac{1}{(\frac{S}{C_{S/L}})}}$$

The equation as used in this report is:

$$\left(\frac{S}{N + C_\omega + C_{S/L}}\right)_j = 10 \log \left[\frac{1}{\frac{1}{\left(\frac{S \cdot I_F}{N}\right)} + \frac{1}{\left(\frac{S \cdot I_F}{C_\omega}\right)} + \frac{1}{\left(\frac{S \cdot I_F}{C_{S/L}}\right)}}\right]$$

E. DEPRESSION ANGLE APPROXIMATION

$R$ = Slant Range, N miles

$h$ = Height, 100's feet

$E^\circ$ = Depression Angle, degrees

therefore

$$R \sin E^\circ = \frac{h}{60.8}$$

let $\sin E^\circ = E_{(Rad.)}$

therefore

$$E_{(Rad)} = \frac{h}{R \quad 60.8} \text{ (Rad)}$$

$$E_{(deg)} = E^\circ = \frac{h}{R \quad 60.8} \quad \frac{360^\circ}{2\pi \text{ Rad}}$$

$$E^\circ = \frac{h}{R} \cdot 942$$

therefore

$$E^\circ \approx \frac{h(100\text{'s feet})}{R(\text{N miles})} \text{ in degrees}$$

## APPENDIX C

## WORK FORM USAGE EXAMPLE

This is an example of usage of the work forms presented in sections A and B. The calculations are for the performance of a radar which has the following characteristics.

### RADAR PARAMETERS

| | |
|---|---|
| P: | 50 kw |
| L: | 13 db |
| $\overline{NF}_o$: | 10 db |
| $\lambda$: | 3.22 cm (X band) |
| Rain: | 1mm/hour |
| Antenna: | AZ = 2°, EL = 2°, Gain = 38 db |
| $\tau$: | 1 $\mu$sec |
| B: | 1 MHz |
| PRF: | 1000 pulses/sec |
| Scan Rate: | 90°/sec |
| Target RCS: | 1000 $M^2$ |
| Radar Height: | 6,000 feet |
| Target Height: | 0 feet |
| Clutter: | sea state 3 |
| Desired Pd: | 90% at PFA = $10^{-4}$ |

# II. CALCULATIONS

## A. MAXIMUM RANGE ESTIMATION

### 1. Single Pulse

| Parameter | Value | Units | db Representation | Multiply By | Add db Results |
|---|---|---|---|---|---|
| $P_k$ : Peak Power | 50 | KW | 17 db | +1 | +17db |
| $\lambda$ : Wavelength | 3.22 | cm | 5.1db | +2 | +10.2db |
| $\sigma_T$ : Target RCS | 1000 | $M^2$ | 30 db | +1 | +30db |
| G : Antenna Gain | 38 | db | → | +2 | +76db |
| L : Losses | 13 | db | → | -1 | -13db |
| B : Bandwidth | 1 | MHz | 0 db | -1 | -0db |
| $\overline{NF}_o$ : Noise Figure | 10 | db | → | -1 | -10db |
| (S/N): Signal/Noise | 16 | db | → | -1 | -16db |
| Conversion Factor | | | | → | -30 |

4 db nautical miles = $SUM_{4R}$ = 64.2 db

The maximum range (N miles) is obtained by multiplying the $SUM_{4R}$ decibel by $\frac{1}{4}$ and expressing this as a ratio:

Maximum Range Estimation = 40 NM

### 2. Comments

a. Chirp Systems

(1). Use peak transmitter power (as at the antenna)

(2). Use the narrow, unchirped bandwidth

b. Antenna Gain

(1). If aperture only is given, see table in Appendix A.

c. Losses

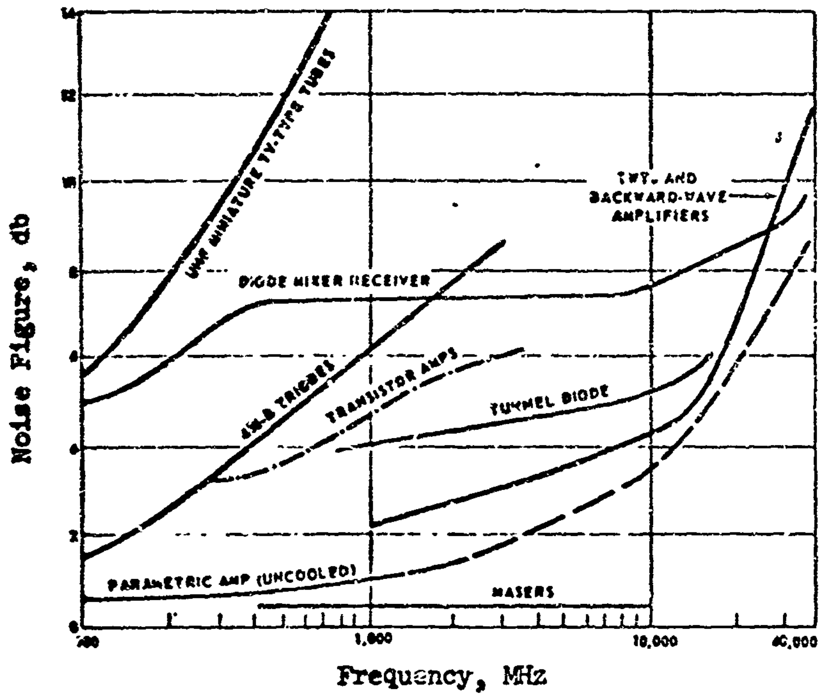
(1). Typical value for search radar 16 db, minimum value 10 db.

(2). Losses included are:

| | | Minimum db |
|---|---|---|
| $L_c$ | collapsing | 2 |
| $L_i$ | integration | 1 |
| $L_e$ | gate or filter overlap | 0 |
| $L_g$ | threshold | 1 |
| $L_d$ | scan distribution | 1 |
| $L_f$ | target | 0 |
| $L_n$ | antenna efficiency | 0 |
| $L_m$ | filter matching | 1 |
| $L_o$ | post detection integration | 1 |
| $L_p$ | antenna pattern | 1 |
| $L_r$ | receiving loss | 1 |
| $L_t$ | transmitting loss | 1 |
| $L_s$ | scanning loss | 0 |
| | | 10 db |

d. Signal to Noise Ratio (S/N). Typical value: 12db. This provides a probability of detection of about 90 percent with a false alarm ratio of .0001. For other values see Appendix A.

e. **Noise Figure.** The following table gives the minimum noise figures that may be expected from different types of detectors. Actual values that may be expected from equipment in the field exceed these values by about 40 percent.




f. PRF Limited Range

| Parameter | Value | Units | db Representation | Multiply By | Add db Results |
|---|---|---|---|---|---|
| PRF | 1500 | pulses/sec | 31.5 db | -1 | -31.5db |
| Conversion Factor | — | — | —— | ——→ | +49.2db |

$U_{db}$, Unambiguous decibel range = +17.7 db

The PRF limited range is the ratio representation of the Unambiguous decibel range, $U_{db}$. Therefore, PRF Limited Range = 60 NM

B. CALCULATION OF $\left(\frac{S}{N + C_\omega + C_{S/L}}\right)_i$ RATIO

1. Preliminary Information for $\left(\frac{S}{N + C_\omega + C_{S/L}}\right)_i$ Calculation

**Limitations:** Radar height less than 10,000 feet.

Target height less than 10,000 feet.

Depression angles less than 10 degrees.

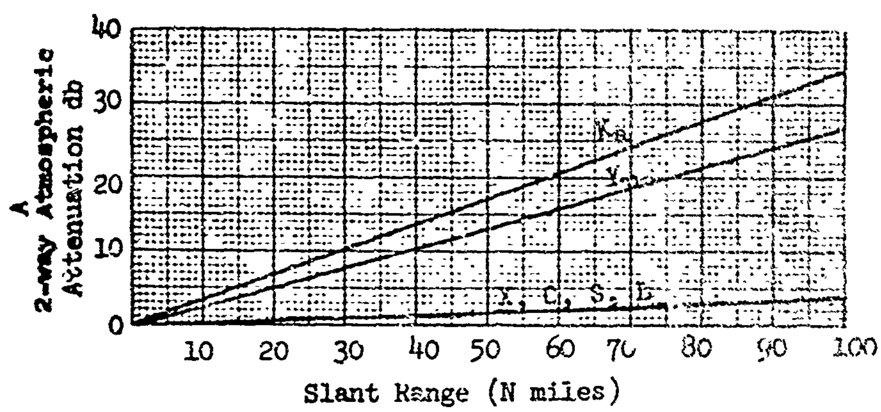
Slant ranges greater than 3 N miles

a. Slant Range, R = 40 n miles

Radar Height, h = 60 (100's feet)

Depression angle, θ°, = $\frac{h \text{ (100's ft)}}{R \text{ (n miles)}}$ = 1.5 degrees.

b. Atmospheric Attenuation, A = 1.0 db.



c. Rain Attenuation

(1)

| Parameter | Value | Units | db Representation | Multiply By | Add db Results |
|---|---|---|---|---|---|
| R : Range | 40 | NM | 16 db | +1 | +16 db |
| W : Rain Rate | 1 | mm/hr | 0 db | +1 | 0 db |
| λ : Wavelength | 3.22 | cm | 5.1 db | -2 | -10.2 db |
| Factor | | | | | -1.42 |

$SUM_R$ = 4.4 db

(2)

| Parameter | Value | Units | Ratio Representation | $A_R$ |
|---|---|---|---|---|
| $SUM_R$ | 4.4 | db | 2.8 | 2.8 |

$A_R$, 2-way Rain Attenuation = 2.8 db

2. Calculation of (S/N)i

a. Single Pulse $(S/N)_1$

| Parameter | Value | Units | db Representation | Multiply By | Add db Results |
|---|---|---|---|---|---|
| $P_k$ : Peak Power | 50 | Kw | 17 db | +1 | +17 db |
| $\lambda$ : Wavelength | 3.22 | cm | 5.1 db | +2 | +10.2 db |
| $\sigma_T$ : Target RCS | 1000 | $M^2$ | 30 db | +1 | +30 db |
| G : Antenna Gain | 38 | db | | +2 | +76 db |
| L : Losses | 13 | db | | -1 | -13 db |
| A : Atmospheric Attenuation | 1 | db | | -1 | -1 db |
| $A_R$ : Rain Attenuation | 2.8 | db | | -1 | -2.8 db |
| $\overline{NF}_o$ : Noise Figure | 10 | db | | -1 | -10 db |
| B : IF Bandwidth | 1 | MHz | 0 db | -1 | -0 db |
| R : Range | 40 | NM | 16 db | -4 | -64 db |
| Factor | | | | | -30.0 db |

$(\frac{S}{N})_1$ = 12.4 db

b. Integration Improvement (Assuming visual PPI detection)

PRF = 1500 pulses/second

AZ° = 2 degrees

SCAN RATE 90 degrees/second

number of Hits/Scan, $\#H = \frac{(PRF)(AZ°)}{(SCAN\ RATE)}$ = 33 Hits/Scan

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| #H, (Hits/Scan) = | 5 | 10 | 15 | 20 | 25 | 30 | 40 | 50 | 60 |
| I, Integration Improvement in db = | 6 | 8.4 | 9.6 | 10.5 | 11.2 | 11.8 | 12.6 | 13.2 | 13.8 |

Integration Improvement, I = 12 db

c. Integrated $(S/N)_i$

$$(\frac{S}{N})_i = (\frac{S}{N})_1 (db) + I db = 24.4 \text{ db}$$

3. Calculation of $\left(\frac{S}{C_\omega}\right)_i$

a. Single Pulse $(S/C_\omega)_1$

| Parameter | Value | Units | db Representation | Multiply By | Add db Results |
|---|---|---|---|---|---|
| $\sigma_T$ : Target RCS | 1000 | $M^2$ | 30 db | +1 | +30 db |
| $\lambda$ : Wavelength | 3.22 | cm | 5.1 db | +4 | +20.4 db |
| W : Rain Rate | 1 | mm/hr | 0 db | -1.6 | -0 db |
| AZ : AZ Beamwidth | 2 | deg. | 3 db | -1 | -3 db |
| EL : EL Beamwidth | 2 | deg. | 3 db | -1 | -3 db |
| $\tau$ : Pulse Length | 1 | $\mu$ sec | 0 db | -1 | -0 db |
| R : Range | 40 | NM | 16 db | -2 | -32 db |
| Factor → | | | | | + 4.87 db |

$(S/C_\omega)_1$ = 17.3 db

b. Integration Factor

Integration Improvement, I, from 2b. = 12 db

c. Pulse Compression Ratio

Pulse Compression Ratio = 1 unitless

The Pulse Compression Factor, CR, is the decibel representation of the unitless Pulse Compression Ratio.

Therefore, Pulse Compression Factor, CR = 0 db

d. Integrated $(S/C_\omega)_i$

$$\left(\frac{S}{C_\omega}\right)_i = \left(\frac{S}{C_\omega}\right)_{1db} + I_{db} + CR_{db} = 29.3 \text{ db}$$

4. Calculate $\left(\frac{S}{C_{S/L}}\right)_i$

a. Clutter Reflectivity

(1). Depression Angle, θ, from 1a. = 1.5 deg.

Radar Band = X

Clutter Type = S.S.3

Clutter Reflectivity, $\sigma_o$, from Clutter values Appendix A. = 39 db.

(2). Pulse Compression Effect:

| Parameter | Value | Units | Multiply By | Add db Results |
|---|---|---|---|---|
| $\sigma_o$ : Clutter Reflectivity | 39 | +db | -1 | -39 |
| CR : From Sec. 3c. | 0 | +db | -1 | - 0 |

$\sigma_o$(EFF), Effective Clutter Reflectivity = -39 db.

b. Single Pulse $\left(\frac{S}{C_{S/L}}\right)_1$

| Parameter | Value | Units | db Representation | Multiply by | Add db Results |
|---|---|---|---|---|---|
| $\sigma_T$ : Target RCS | 1000 | $M^2$ | 30 db | +1 | +30 db |
| τ : Pulse Length | 1 | μsec | 0 db | -1 | -0 db |
| R : Range | 40 | NM | 16 db | -1 | -16 db |
| AZ : AZ Beamwidth | 2 | deg. | 3 db | -1 | - 3 db |
| $\sigma_o$(EFF): From Sec. 4a. | -39 | db | | -1 | +39 db |
| Factor | | | | | -35.35 db |

Single Pulse $\left(\frac{S}{C_{S/L}}\right)_1$ = 14.6 db

c. Integrated $\left(\frac{S}{C_{S/L}}\right)_i$

$\left(\frac{S}{C_{S/L}}\right)_1$ (from Sec. 4b.) = 14.6 db

I (From Sec. 2b.) = 12 db

$\left(\frac{S}{C_{S/L}}\right)_i = \left(\frac{S}{C_{S/L}}\right)_1 + I =$ 26.6 db

5. Calculate $\left(\frac{S}{N + C_\omega + C_{S/L}}\right)_i$

a. Calculate "Energy" Ratio

| Parameter | Value | Units | Multiply By | Add Ratio Representation |
|---|---|---|---|---|
| $(S/N)_i$: Section 2c. | 24.4 | db | -1 | .0035 |
| $(S/C_\omega)_i$: Section 3d. | 29.3 | db | -1 | .0015 |
| $(S/C_{S/L})_i$: Section 4c. | 26.6 | db | -1 | .0025 |

E, Inverse "Energy" Ratio = .0075 unitless

b. Integrated $\left(\frac{S}{N + C_\omega + C_{S/L}}\right)_i$

| Parameter | Value | Units | db Representation | Multiply By | $\left(\frac{S}{N+C_\omega+C_{S/L}}\right)_i$ db |
|---|---|---|---|---|---|
| E, Sec. 5a. | .0075 | unitless | -21.3 db | -1 | +21.3 db |

$\left(\frac{S}{N + C_\omega + C_{S/L}}\right)_i =$ +21.3 db

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13. ABSTRACT

This report provides a work form and rationale to perform hand calculations of the radar range equation. The techniques described cover the conventional geometric aspects of the radar equations as well as the effects of rain clutter, rain attenuation, atmospheric attenuation, sea and land clutter, and pulse integration for both conventional pulse and chirp clutter. It is complete, requiring no further texts, tables, references or slide rules.

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